Measurement of the W mass and width at FCC-ee

Contribution to Snowmass 2021

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Abstract

The FCC-ee is a frontier Higgs, Top, Electroweak, and Flavour factory. It will be operated in a 100 km circular tunnel built in the CERN area, and will serve as the first step of the FCC integrated programme towards $\geq$ 100 TeV proton-proton collisions in the same infrastructure [1]. In addition to an essential and unique Higgs program, it offers powerful opportunities for discovery of direct or indirect evidence for BSM physics, via a combination of high precision measurements and searches for forbidden or rare processes, and feebly coupled particles.

A key element of the FCC-ee physics program is the large luminosity in the energies of the Z pole and W pair threshold, coupled with the availability of precise centre-of-mass energy calibration thanks to resonant depolarization up to at least the W pair production threshold. The W mass can be measured with a precision of about 500 keV or possibly less. This Snowmass LOI focuses on the measurement of the W mass and width. The ultimate goal, that experimental and theory systematic errors match the statistical accuracy, leads to highly demanding requirements on detector design and on theoretical calculations. This letter of interest describes some of the many challenges presented by these benchmark measurements.

Thematic Areas:

- (EF04) EW Physics: EW Precision Physics and constraining new physics
- (EF05) QCD and strong interactions: Precision QCD

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The W mass is one of the most important and sensitive electroweak precision observables. At FCC-ee it will benefit of the availability of accurate beam energy calibration by resonant depolarization at the W-pair production threshold energy [2]. It is estimated [3, 4] that a statistical precision around 400 keV on the W mass, and around 1 MeV on the W width can be achieved from a scan of cross-section measurements at threshold with beam energy calibration uncertainty of 300 keV. The optimal energy points to take data for the best ultimate precision on the W mass and widths are at the $\Gamma_{\rm W}$-independent $E_{\rm CM} = 162.3$ GeV point, and a second lower $E_{\rm CM}$ point at $(1-2)\Gamma_{\rm W}$ units below the nominal $2m_{\rm W}$ threshold, according to if the desired precision is more or less focused on the W mass or the W width measurement. When limiting the data taking to half-integer spin-tune energy points, adequate for energy calibration with resonant depolarization [2], the optimal data taking points are $E_{\rm CM} = 157.3$ GeV and 162.6 GeV. Figure 1 left shows the W-pair production cross section as a function of the energy in the threshold region, with variations of the W mass and width; the $\Gamma_{\rm W}$-independent point near 162.3 GeV is clearly visible. It is generally believed that for these threshold cross section measurements the impact of systematic uncertainties can be kept (well) below the statistical precision. For this it could be useful to take data and measure both signal and background cross section at more than two energy points, in order to reduce background and acceptance uncertainties, cancelling the effects of $E_{\rm CM}$-correlated systematic uncertainties in the W mass and width extraction.

A recent study [5] observed that final state reconstruction and kinematical fit can lead to competitive results, exploiting the reconstruction of W-pair decay products both at threshold and at higher energies. Figure 1 right shows the kinematically reconstructed W mass peak with events produced at the $E_{\rm CM} = 162.6$ GeV threshold. For this kinematical reconstruction method the final impact of systematic uncertainties is currently less clear, in particular uncertainties connected to the modelling of the W hadronic decays. The use and interplay of $Z\gamma$ and ZZ events, reconstructed and fitted with the same techniques as the WW events, will be important for the extraction of W mass measurements with data at the higher $E_{\mathrm{CM}} = 240$ and 365 GeV.

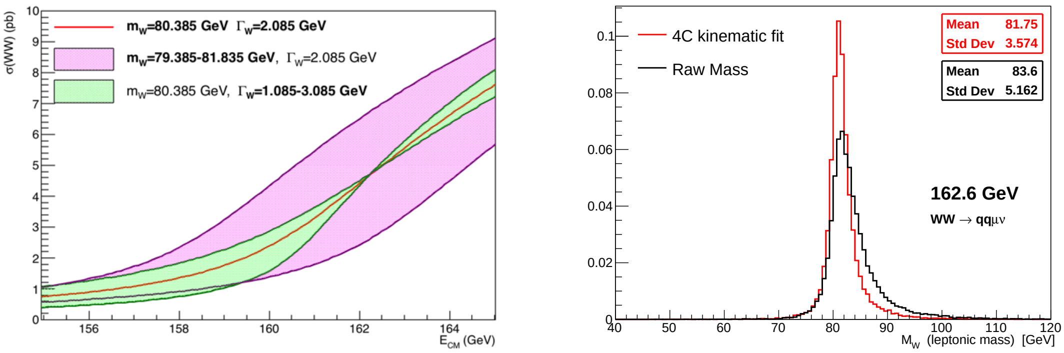

Figure 1: (Left) W-pair production cross section as a function of the e^+e^- collision energy E_{CM} as evaluated with YFSWW3 1.18 [6]. The central curve corresponds to the predictions obtained with $m_{\mathrm{W}} = 80.385$ GeV and $\Gamma_{\mathrm{W}} = 2.085$ GeV. Purple and green bands show the cross section curves obtained varying the W mass and width by ± 1 GeV. (Right) Reconstructed W mass distributions in the semi-leptonic decay channel with the CLD detector at the FCC-ee for $E_{\mathrm{CM}} = 162.6$ GeV with and without a kinematic fit [5].

Tthe comparison and combination of results from both methods will be of great interest and might lead to a further significant final improvement of the W mass and width precisions.

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